Study on Fuel Leakage Measurement System of Fuel Cell Vehicles

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ABSTRACT

Recently, the fuel cell vehicles (FCV) are actively developed in the world. JARI has been done and examined the basic data for FCV standardization as the entrustment of NEDO (New Energy and Industrial Technology Development Organization) from 2000. We have been examined the safety evaluation methods of fuel leakage at the normal usage condition and the collision condition, so that FCV use the compressed hydrogen gas as the fuel source.

We have done the crash test using the moving barrier as simulated FCV to examine the fuel leakage measuring method, as one of the safety evaluation methods of FCV. We examined the fuel leakage detection using the flow meter measurement method, as one of the fuel leakage measurement methods.

The result is as follows.

-Sample fuel cell stack is not scattered.

-In the measurement with the flow meter, the gas leakage was undetectable.

1. INTRODUCTION

With the growing concern about environmental problems such as global warming and atmospheric pollution, FCV have drawn considerable attention. Their use would greatly reduce atmospheric carbon dioxide, one cause of global warming, and they emit almost no toxic gases. Thus, vigorous efforts are being made to develop and produce a commercially viable FCV.

However, FCV are currently still in the stage of research and development, and no unified criteria, standards, and test methods have been established for the testing of vehicles and parts. Moreover, as actual FCV are produced and come into greater use in unspecified numbers in the near future, it will be necessary to set guidelines regarding the safety and reliability of these vehicles. FCV that use hydrogen as fuel are seen as the ultimate clean vehicle. However, the lack of studies on such vehicles in automobile-related fields means that many points of uncertainty remain with regard to their safety in practical use. To avoid an increase in deaths from unforeseen types of accidents accompanying the wider use of FCV, immediate efforts are needed to begin formulating safety guidelines.

In the light of this situation, in we began a Fuel Cell Infrastructure Project commissioned by the New Energy and Industrial Technology Development Organization (NEDO). FCV are seen as a promising means of transportation for the 21st century, and the aim of this project is to develop various tests and assessment methods needed to improve the distribution infrastructure for stationary fuel cells and these vehicles. The findings obtained from these tests and other means are also meant to contribute to the standardization and establishment of criteria and standards, both at home and abroad.

In the following, we report the results from a series of experiments conducted with the aim of developing methods to test for fuel leakage, and to promote the safety of fuel cell vehicles during collisions.

2. EXPERIMENTS AND METHODS

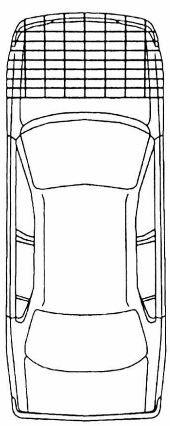
From the viewpoint of occupant protection, the collision safety of fuel cell vehicles is not considered to be different from that of conventional vehicles. However, fuel cell vehicles use hydrogen gas as fuel, so fuel leakage in collisions involving fuel cell vehicles must be investigated using the fuel leakage test and measurement methods adopted for gas fuels. More to the point, this is not feasible at the current stage of FCV development. Moreover, since the structure and arrangement of parts in FCV are not standardized, fuel leakage cannot be investigated using test vehicles. Therefore, we decided to build a simulation vehicle incorporating crashworthiness and a high pressure container for the fuel tank (Figure 1), for the purpose of investigating methods of measuring leaks during collisions in the fuel supply system, from the high pressure containers to the fuel stacks.

Considering a series of investigations based on the FMVSS[1)2)3)], for which the results of fuel leakage test methods for compressed natural gas (CNG) automobiles are available, we adopted the type of moving barrier used in FMVSS214 for the basic structure of the simulation vehicle. To simulate the front deformation characteristics of the simulation vehicle at a collision speed of 48 km/h, a honeycomb barrier face was attached. Since the barrier face characteristics were insufficient for use with only the FMVSS214 at that speed, another honeycomb barrier face was added to the rear section of the FMVSS214 barrier face to obtain the energy absorption characteristics shown in Figure 2. That honeycomb barrier face was then attached to the front of the moving barrier. The crash test conditions were a full-wrap frontal collision at a speed of 48 km/h (Figure 3).

The simulation vehicle was equipped with a simulation fuel supply system to investigate methods for measuring fuel leakage from fuel cell stacks, and a high-pressure gas container to investigate the conditions for equipping vehicles with them as well.

The structure of the simulation vehicle is shown in Figure 4, and that of the fuel cell stack in Figure 5.

Figure 1. Test vehicle



Permanent deformation (m)

Bonnet (FF) — 0.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8

283	283	283	283	283	283	283	283
232	232	232	232	232	232	232	232
300	300	300	300	300	300	300	300
369	369	369	369	369	369	369	369
438	438	438	438	438	438	438	438
506	506	506	506	506	506	506	506
575	575	575	575	575	575	575	575

Cab orver — 0.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7

626	626	626	626	626	626	626	626
343	343	343	343	343	343	343	343
417	417	417	417	417	417	417	417
491	491	491	491	491	491	491	491
566	566	566	566	566	566	566	566
640	640	640	640	640	640	640	640

Pick up — 0.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8

434	434	434	434	434	434	434	434
256	256	256	256	256	256	256	256
315	315	315	315	315	315	315	315
374	374	374	374	374	374	374	374
433	433	433	433	433	433	433	433
492	492	492	492	492	492	492	492
551	551	551	551	551	551	551	551

Permanent deformation (m)

Bonnet (FR) — 0.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8

279	279	279	279	279	279	279	279
265	265	265	265	265	265	265	265
353	353	353	353	353	353	353	353
441	441	441	441	441	441	441	441
528	528	528	528	528	528	528	528
616	616	616	616	616	616	616	616
704	704	704	704	704	704	704	704

Semi-Cab — 0.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8

259	259	259	259	259	259	259	259
244	244	244	244	244	244	244	244
325	325	325	325	325	325	325	325
405	405	405	405	405	405	405	405
486	486	486	486	486	486	486	486
566	566	566	566	566	566	566	566
647	647	647	647	647	647	647	647

Off-road — 0.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7

380	380	380	380	380	380	380	380
371	371	371	371	371	371	371	371
497	497	497	497	497	497	497	497
622	622	622	622	622	622	622	622
747	747	747	747	747	747	747	747
873	873	873	873	873	873	873	873

Figure 2. The energy absorption characteristics [4]

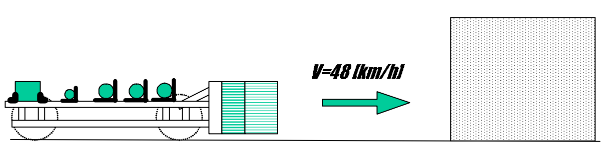


Figure 3. Test condition

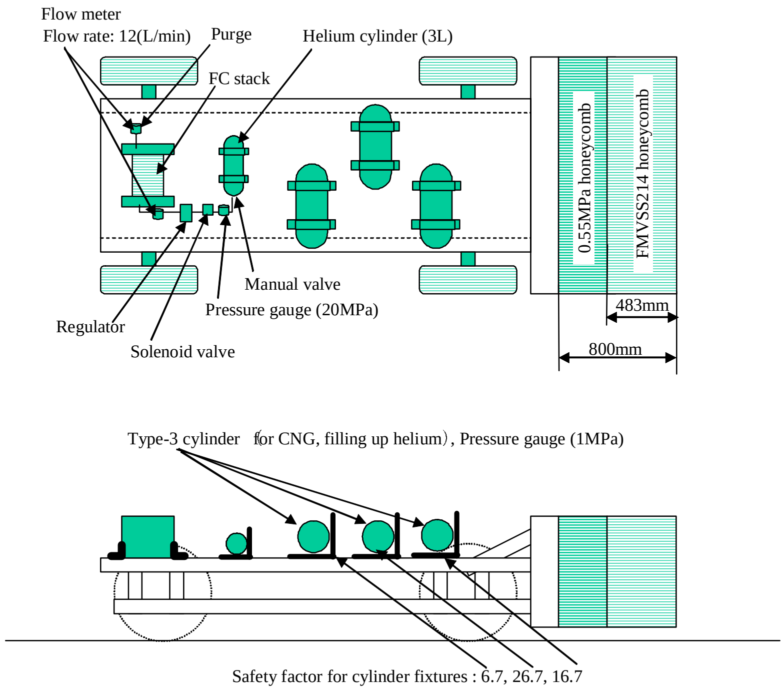


Figure 4. The structure of the test vehicle

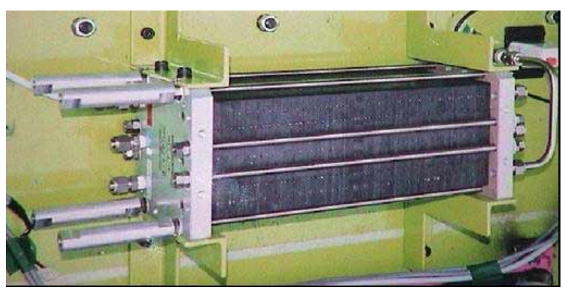


Figure 5. Fuel cell stack

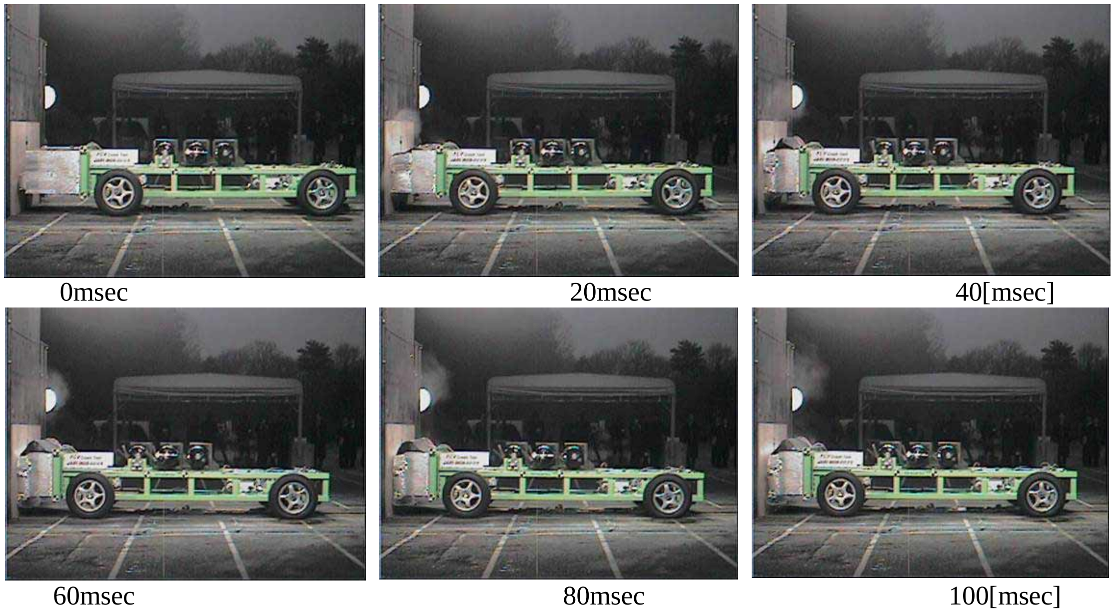
The design strength of the attachment fixtures for the 3 high-pressure gas container carriages attached to the simulation vehicle was set at 6.7 times, 16.7 times, and 26.7 times the mass of the respective container including the weight of the gas at static strength. The design strength (safety factor) of the attachment fixtures was set assuming impacts of 10 G, 25 G, and 40 G, respectively, with a dynamic intensity 1.5 times that of the static strength, and iron as the fixture material.

3. SIMULATION VEHICLE FRONTAL COLLISION TEST RESULTS AND DISCUSSION

Figure 6 shows the collision progress with high-speed video camera.

The total length of the honeycomb barrier material attached to the front section of the vehicle was 800 mm. The front portion of this was FMVSS214, and additional honeycomb barrier was attached at the rear to further increase strength. The test results showed that by 40 msec after the impact nearly the entire FMVSS214 portion of the front section had lost its shape, but there was little deformation of the rear honeycomb section added for this test. Further adjustment of strength is necessary.

Figure 7 is a line graph plotting the composite acceleration of the 3 axes of the simulation stack center of gravity and the center of gravity of the simulation vehicle frame.



(Safety factor for the cylinders from left side

: 6.7, 26.7, 16.7)

Figure 6. Collision progress with high-speed video camera

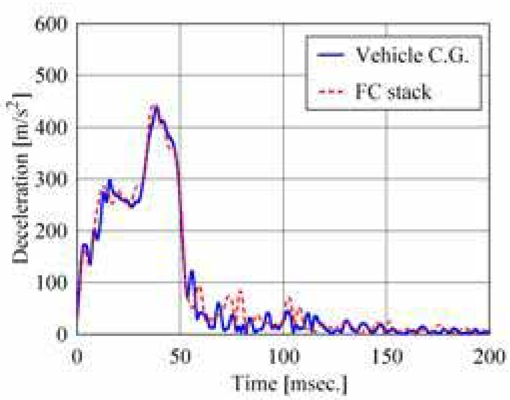


Figure 7. Deceleration – time curves of vehicle C.G

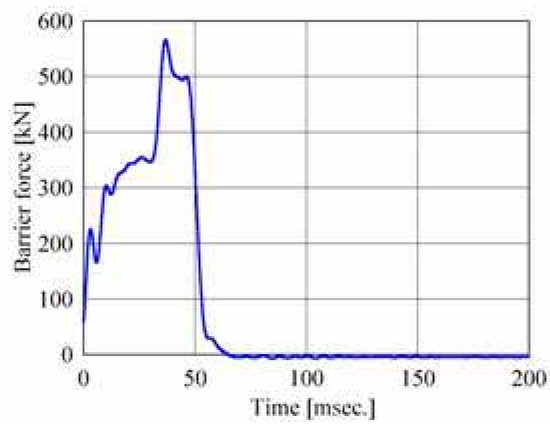


Figure 8. Barrier force – time curve

In the front impact test with the simulation vehicle, deformation was seen only in the honeycomb barrier material attached to the front section of the carriage. Since there was no deformation in the other parts of the vehicle, the vehicle center of gravity corresponded closely to the composite acceleration of the 3 axes of the fuel cell stack firmly secured to the vehicle.

Next, Figure 8 plots the barrier load against time obtained in the test.

The barrier load suddenly increases starting 30 msec after impact. The timing of this section is virtually the same as for the FMVSS214 honeycomb barrier face when bottoming out. The reason the load exceeded calculations is probably that the barrier material, which was added using calculations based on the vehicle absorption energy distribution graph, did not deform because its strength had been increased according to the strain rate dependence. To continue front impact tests of simulation vehicles focusing on fuel leakage from the fuel cell stack, it will be necessary to further investigate the characteristics of the added barrier material.

Next, to investigate methods to measure leakage from the fuel cell stack, the leakage rate in the fuel cell stack outlet/inlet flow volume before, during, and after the test is shown in Figure 9.

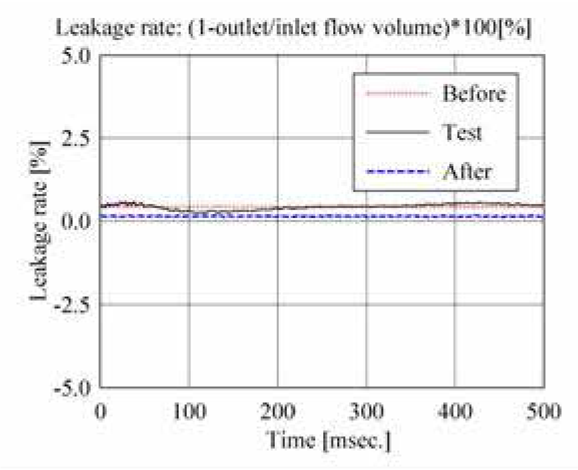


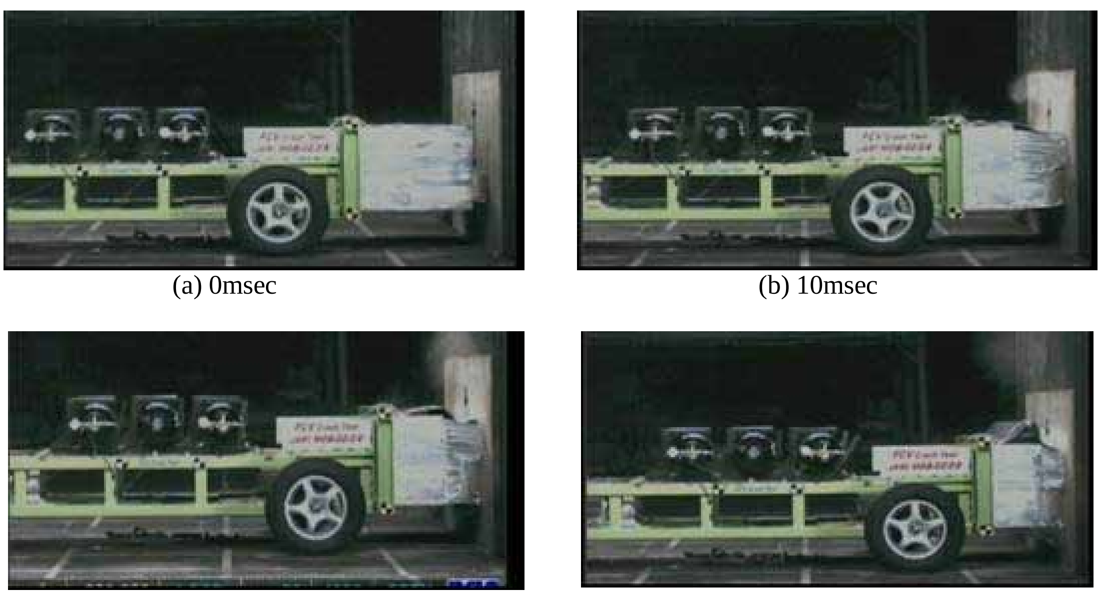
Figure 9. Leakage rate in the fuel cell stack outlet/inlet flow volume

No external damage appeared in the fuel cell stack from the impact in the crash tests. Flow measurements of the upper flow of the fuel cell stack and excessive flow of helium were successfully conducted. The leakage rate indicates that the leakage from the fuel cell stack was below the 1% level, within the error range of the measuring instrument. Thus, from the present experiment no phenomena were seen to suggest an increase in fuel leakage from the fuel cell stack at the time of impact. The fluctuations in the leakage rate during the experiment were outside the response range of the flow meter (responsiveness: 1 Hz), so there was not thought to be any considerable fluctuation in the leakage rate.

Methods were investigated to measure fuel leakage assuming the power generation status of the fuel cell stack. However, a flow rate meter with a high impact resistance and superior response and linearity is needed to measure the flow rate directly. Measuring flow fluctuations within the short time frame of an impact test is very difficult, and we realized that direct measurements of flow rate are not a practical method for determining leakage.

Future investigations are needed on methods to measure such parameters as pressure, gas recovery, and electric current method.

Next, considering tank attachment conditions, the photos in Fig. 10 show the time deformation starts during collisions with tank attachment fixtures of differing design strengths.



(a) 0msec (b) 10msec

(c) 22msec (d) 42msec

Figure 10. Deformation start timings

The fuel tank attachment support frameworks (beginning with upper left) had static safety rates set at 6.7, 26.7, and 16.7, respectively. Ten msec after the impact, deformation was seen in the fixture with a safety rate of 6.7. Deformations of the attachment support framework were seen 22 msec after impact with the 16.7 fixture, and at 42 msec with the 26.7 fixture. The deceleration at the time deformation could be determined was approximately 15 G, 40 G, and 27 G in the respective attachment support frameworks. No deformation was seen with each of the support frameworks, and the tanks remained fixed until deceleration reached 1.5 times the static safety rate.
Figure 11 shows the deceleration wave pattern in the longitudinal (x-axis) direction of the vehicle body at the center of gravity of the simulation vehicle used in the tests, and that of an actual vehicle, at the time of the frontal collision.

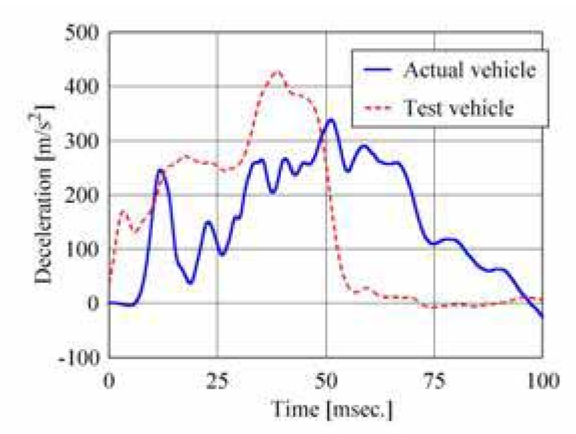


Figure 11. Deceleration curves in x-axis of the test vehicle and that of an actual vehicle

With the actual vehicle, deceleration of the vehicle center of gravity in the x-axis direction began about 10 msec after impact and continued until about 100 msec. Deceleration in the simulation vehicle, on the other hand, began immediately upon impact and was close to zero by 60 msec. Thus, there was a considerable difference between the deceleration in the actual vehicle and simulation vehicle, particularly about 30~50 msec after impact. This is thought to correspond to the time when the deformation of the FMVSS214 honeycomb barrier material is finished, and the added honeycomb barrier material comes into action.
The impact absorption material in the present front impact test, in addition to the FMVSS214 honeycomb barrier face, included additional honeycomb having characteristics obtained from the vehicle absorption energy distribution chart. However, the characteristics of the added honeycomb could not perfectly simulate the actual vehicle, so further improvements are needed.

4. CONCLUSION

Following is a summary of results obtained from the front impact tests using the simulation vehicle to investigate methods of measuring fuel leakage from the fuel cell stack at the time of impact:

- No external damage from the impact was seen to the fuel cell stack used in the present experiments.
- No fuel leakage was seen from measurements of flow rate.
- However, considering the movement and deformation of components such as the fuel container that occur with impact, crash tests with an actual vehicle will be needed in the end to test fuel leakage, even when design conditions for the fixation of components have been established.

Because of the very high cost of FCV today, the use of simulation vehicles is an effective way to investigate methods of testing fuel leakage. In the future, while improving the impact characteristics of simulation vehicles, further investigations will be needed on methods to measure fuel leakage in line with the pressure methods used and other factors, as well as the alternative fuels used in crash tests.
Furthermore, to assess the leakage of hydrogen, for which little field-proven data are available regarding its use as an automobile fuel, studies of ways to conduct safety tests assuming large-scale leaks during the test with fuel alternatives other than gas will be crucial.

REFERENCES

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